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# PROCEEDINGS

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# DISCUSSION OF PROCEEDINGS PAPERS

404, 462, 620, 623, 728

IRRIGATION AND DRAINAGE DIVISION



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Discussion of
"IRRIGATION POTENTIALITIES IN ARKANSAS"

by Paul H. Berg
(Proc. Paper 404)

PAUL H. BERG,[1] A.M. ASCE.—The writer concurs generally with the remarks of Mr. Hargreaves. It is true that irrigation in humid areas is not new. The irrigation of rice in Arkansas commenced in 1904 and the acreage irrigated has increased steadily since that time.

Mr. Hargreaves' statement, "The assumption by Mr. Berg that future crop distribution will be the same after irrigation development gives too conservative a picture of future benefits," is not concurred in by the writer. Much of the potentially irrigable acreage has been farmed without irrigation since before the Civil War, with farming practices and crop rotations becoming well established and virtually fixed. The planning of an irrigation project and determination of its feasibility based upon the conversion to production of different crops and crop rotations would place too much reliance upon the success of agricultural education. It may be true that over a period of 30 to 60 years there could be appreciable change in such cropping practices. To develop an irrigation project based upon the assumption that there would be an immediate change would certainly doom the project to early financial failure.

The foregoing is not an attempt to belittle the value of education in agricultural practices to the success of an irrigation development. It is only recognition of the fact that although the better farmers will rapidly develop crops which yield the highest net income, the vast majority will convert to such crops only after the success of conversion has been thoroughly demonstrated. At a development farm in the sub-humid area of Kansas, irrigated land produced yields of well over 100 bushels per acre of corn and over 7 tons per acre of alfalfa hay. This does not necessarily mean that similar yields could be expected throughout the project area. It merely demonstrates that by following good irrigation and agricultural practices, unusually high yields may be produced.

Mr. Hargreaves' remarks provoke much thought and the writer agrees that education in the best irrigation practices and the best cropping practices is fundamental to the success of an irrigation project in humid areas.

The remarks of Mr. C. O. Clark were difficult to understand and cannot be concurred in by the writer. Mr. Clark, when working for the Corps of Engineers at Tulsa, Oklahoma, was completely familiar with the activities of the Legislature of the State of Arkansas with respect to development of an adequate water code. For the past four years, the Legislature has had an interim committee studying this problem because it recognized that there are now conflicts in the beneficial use of water for irrigation and that undoubtedly such

1. Projects Mngr., Kansas River Projects, Bureau of Reclamation, U. S. Dept. of the Interior, McCook, Nebr.

conflicts will increase as time goes on. The matter of water rights has been the subject of numerous discussions between the writer and representatives of the Arkansas State government. In 1951 and 1952, an attorney working for the Bureau of Reclamation was requested to assist, and did assist, a legislative committee in preparing water right legislation which recognized the doctrine of appropriation. The bill was not submitted to the 1953 Legislature because it was not considered to have been adequately studied by all of the interested people of the State.

Since Mr. Clark has long been familiar with the foregoing, the purpose of his remarks is beyond the comprehension of the writer.

Discussion of
"A CONCEPT OF LACEY'S REGIME THEORY"

by Ning Chien
(Proc. Paper 620)

GERALD LACEY.[1]—The author correctly states that the dimensions and slope of an alluvial channel, of a given discharge Q, must depend on the sediment load and the bed material size: his suggestion that a certain combination of the variables may depend very little on the sediment load is valuable and most illuminating. The writer will show that in certain combinations the sediment load is entirely absent.

It was Inglis and Lane who first stressed the importance of transported load as opposed to the size of bed material. The precise manner in which both variables enter regime equations has yet to be determined. The author's paper marks an advance in the solution of this problem.

The writer's basic equation for the silt factor is

$$V = 1.155\, f^{1/2} R^{1/2} \;;\quad f = 0.75\, V^2/R \quad . \quad . \quad . \quad . \qquad (A)$$

Had the mean depth D been employed instead of R the hydraulic mean depth the silt factor would have been a function of the Froude number. There are good grounds for concluding that the writer's relationship ought to have taken this form.

The writer also proposed the formula

$$f = 1.76\, m^{1/2} \qquad . \quad . \quad . \quad . \qquad (B)$$

for the size of the bed material particle in millimetres. It was soon realized that the bed load should enter both equations and that as they stood they could apply only to channels which transported an assumed constant, or regime, bed load.

The writer's flow equation in terms of V, R and S

$$V = 16.0\, R^{2/3} S^{1/3} \qquad . \; . \; . \quad . \quad . \qquad (C)$$

contained no silt factor or rugosity coefficient it being considered that such variables were implicit in the actual depth and slope which the channel in loose alluvium adopted. Inglis was the first to contend, with success, that although the bed material size might be implicit the bed load could by no means be ignored in this relationship.

The writer's equation for the wetted perimeter

1. Surrey, England.

$$P = 2.67\,Q^{1/2} \quad . \quad . \quad . \quad . \quad . \qquad (D)$$

which Leopold and Maddock have so remarkably confirmed in respect of the power of 1/2 for natural channels, has the same defect. The precise grade of bed material does not appear to affect the constant but as Inglis and Lane have frequently emphasized the bed load is a most important variable and should enter this equation. With a regime bed load the constant, were it not for the complication of stiff banks, would be approximately correct. In rivers the width varies greatly from point to point and the flow is rarely concentrated into one compact stable channel of minimum width. The writer would now prefer to employ the water surface width W as a variable rather than the wetted perimeter P a procedure which is more in accordance with modern practice.

If we combine equations (A) and (C) a number of silt factors can be obtained of which the following are examples

$$f_{VR} = 0.75\,V^2/R\,,$$
$$f_{RS} = 192\,R^{1/3}\,S^{2/3}\,,$$
$$f_{RS/V} = 3072\,RS/V\,.$$

The author has employed the first two of these silt factors and from them we can derive the third thus

$$f_{RS/V} = f_{RS}^{\;3/2} \,/\, f_{VR}^{\;1/2} \quad . \quad . \quad . \qquad (E)$$

We are now in a position to determine the relationship between $f_{RS/V}$ and the sediment concentration which the author would have derived had he attempted it. If reference is made to Figs. 6 and 7 of the paper and we examine their general trend it will be seen that for a sandy bed material of mean diameter 0.25 mm. we obtain the equations

$$f_{VR} = \text{const.}\,(q_t/q)^{1/2}$$
$$f_{RS} = \text{const.}\,(q_t/q)^{1/6}$$

the first being the mean of the entire range and the second applying to sediment concentrations exceeding 1000 ppm. We must therefore conclude that the parameter RS/V is independent of the sediment concentration $q_t/q$.

This combination of the variables is embodied in the flow equation

$$V = 3072\,RS/f$$

and on replacing f by the square root of the particle size,

$$V = \text{const.}\,g^{1/2}\,RS/\,m^{1/2} \quad . \quad . \quad . \qquad (F)$$

which is none other than the Lacey-Malhotra equation published in 1939.

This dimensionally homogeneous equation has clearly a physical significance. It implies a loose moving bed of incoherent material and a linear resistance law. Although the writer now prefers to express width and depth

in terms of W and D, rather than P and R, the hydraulic mean depth should enter the linear resistance law flow equation since the slope S is involved. The value of R, the effective hydraulic mean depth, being obtained by dividing the cross sectional area, WD, by the effective wetted perimeter—due allowance being made for the different, and usually finer texture of the banks. The point is of importance in all model work.

The recent work of Inglis consists, in his own words, of adding the sediment load as a variable to the Lacey regime equations and this he has done in an original and ingenious manner. The variable m is retained by Inglis but in addition he employs the terminal velocity of the particle in water, $V_s$, and uniformly associates 'X', which is equal to $q_t/q$, with the terminal velocity by means of the product $XV_s$.

The following equations, or Inglis-Lacey formulae as Inglis terms them, repay study. It should be noted that since all involve the discharge they all involve the sediment load

$$V = \text{const. } m^{1/12} (XV_s)^{1/12} Q^{1/6} ,$$
$$D = \text{const. } m^{1/6} Q^{1/3} / (XV_s)^{1/3},$$
$$S = \text{const. } m^{5/12} (XV_s)^{5/12} / Q^{1/6},$$
$$W = \text{const. } (XV_s / m)^{1/4} . Q^{1/2} .$$

By employing all four equations grade, terminal velocity and bed load can be eliminated and the equation

$$V^4 = \text{const. WDS}$$

which is somewhat foreign to the present discussion, results.

On eliminating $(XV_s)$ from the equations we obtain

$$V/DS = \text{const. } / m^{1/2} \quad . \quad . \quad . \quad (G)$$

which should be compared with the previous equation (F), and we can also derive

$$V^3/W = \text{constant } m^{1/2} \quad . \quad . \quad . \quad . \quad (H)$$

These two expressions entirely independent of the sediment load are certainly provocative and should stimulate research.

The comparable Blench equation

$$V^3/W = s \quad . \quad . \quad . \quad . \quad . \quad . \quad (I)$$

in which s is a "practical side factor" incorporating the texture of banks which may be smooth and coherent is a device that has no application to a channel which has formed itself in loose incoherent alluvium and of which the banks also consist of material transported by and thrown down at the sides, by secondary flow, by the channel itself. Blench's side factor is real in nature, where the banks may be of material quite foreign to the alluvium transported but it has no bearing on the basic regime problem of self deposition. It is merely an added complication that must be borne in mind.

The Inglis equation

$$V^2/ gD = \text{const.} (XV_s)^{1/2} \quad . \quad . \quad . \quad (J)$$

in which the diameter of the particle does not enter has yet to be verified. We have however seen that when medium sand forms the bed material the author's figures lend support to the power of 0.5 and the author's equation (6) also lends support to the power of 0.5 for the $V_s$ which in this instance varies as the diameter. What is more important is to verify whether this equation is correct when applied to coarser material. It is possible that the eventual relationship derived may take a somewhat different form.

The author has done a service to the profession in aligning the work of Dr. Einstein on the bed load function with regime theory. The valuable paper of Leopold and Maddock should be concurrently studied by those who desire to review the whole field of investigation. To the writer it is a source of pleasure to find that his regime theory is of interest to research workers in America and hopes that from regime equations, empirical and imperfect though they may be, formulae of physical significance may ultimately be derived.

E. W. LANE,[1] M. ASCE—Dr. Chien's paper is a valuable contribution to the evaluation of the science of design of stable irrigation canals, which has been going on since Kennedy proposed his equation in 1895.[2] Kennedy, Lacey and the others who followed Kennedy developed a method of canal design which was very successful in the plains region of India, where these men worked, and has been very helpful in solving many problems of stream control as well. It was an accomplishment of which those who contributed have ample reason to be proud. However, it has not proved generally applicable, and has not been widely used in Egypt and the United States and is not universally used in India.[3]

The writer believes(8) that the principal weakness of the Lacey relations is that it does not consider the concentration of the sediment as a variable. That sediment concentration should also be included is held by some engineers of India including Sir Claud Inglis and Kanwar Sain. By comparison with the results of the Einstein relations, Dr. Chien finds that Lacey's $f_{vR}$ is a function of the sediment concentration, which also supports this view. The writer believes, however, that Dr. Chien's third conclusion that use of the Lacey formula should be limited to India and Pakistan, should be further limited to the plains sections of those countries, where the relations were developed, since there are parts of these countries where the conditions differ widely from those in the plains sections. Even in these plains sections the conditions are likely to change, since water storage in reservoirs is being introduced, which will change the sediment concentration materially in the canals supplied from them. Calling attention to the limitation of the Lacey relations in Dr. Chien's

1. Hydr. Engr., Fort Collins, Colo.
2. The Prevention of Silting in Irrigation Canals - R. G. Kennedy Minutes of Proceedings of the Institution of Civil Engineers Vol. 119, 1895. pp. 281-290.
3. The Canal System of the Hirakud Project E. P. Pilla and K. C. Thomas Indian Journal of Power and River Valley Development. Vol. IV, No. 10 1954. pp. 59-64.

paper is, therefore, particularly timely. Judging from the experience in the Imperial Valley of California, where the reduction of the sediment load in the Colorado River water by reservoirs and sediment control works materially altered the regime of the canals, changes of a similar nature can be expected in canals in India and Pakistan. In the Imperial Valley the slopes of the canals were reduced as much as two-thirds, and the depth increased as much as 100%. Extensive protection of existing drops and the addition of numerous new ones were required. Similar, but perhaps not so severe, changes will take place when reservoir water is introduced into the canals of India and Pakistan which formerly carried heavy sediment loads.

Dr. Chien tacitly assumes the reliability of the Einstein bedload function, and that when the results obtained by the use of Lacey's relations differ from those obtained by the use of this function, Lacey's relations are in error. This is understandable in view of the author's experience in the use of Einstein's function, but it may not be very convincing to those who have extensive and favorable experience with the Lacey relation and little or no experience with Einstein's function. The writer believes that perhaps the greatest need in the sediment engineering field at the present time is extensive field measurements of the amount of sediment transported in channels under a wide range of conditions, with which the relations proposed by Einstein and others may be checked and the extent of their reliability determined. We are now in the same state with regard to sediment transportation that we were in the early years of this century in knowledge of the flow of water in channels. We need papers containing extensive data on sediment transport comparable to those in the field of channel flow by Ganguillet and Kutter, Scobey and Houk, to enable us to evaluate present formulas, and if they are not adequate, devise better ones. For the solution of our sediment problems we must learn to handle the flow of sediment quantatively just as we handle the flow of water.

Dr. Chien has shown that on the basis of the Einstein function Lacey's $f_{RS}$ is a function of $D^{0.45}$. The results as shown in Figs. 4 and 5 are in rough agreement with the relation Lacey gave of $f = 8\sqrt{D \text{ (in inches)}}$ and later perfected to $f = 8.85\sqrt{D}$. Lacey did not advocate the use of this relation, perhaps because it did not work out when applied to $F_{VR}$.

In selecting relations for use in irrigation canal design those engaged in perfecting the science of canal design should keep in mind that the objective desired is to find the canal which will be most economical from the stand point of initial cost and maintenance. To minimize maintenance, the canal must not be subject to deposit or scour in objectionable amounts. The regime theory of design came into use because it aimed to provide freedom from both the scour and the deposit, but it did not consider the element of first cost. When our knowledge of sediment transportation increases, it may be possible to find channels of lower total cost (first cost plus maintenance) which will be somewhat different in characteristics from channels which would be naturally formed by the water when flowing under equilibrium conditions. The regime relations were developed because the maintenance problem, usually due to deposit, overshadowed the matter of first cost, and the regime approach offered what was the only course which then had a prospect of being successfully devised to handle the problem of sediment deposit. Where clear water from reservoirs is involved, however, the problem of deposit is eliminated, since if scour is prevented, no sediment will be present to be deposited. The analysis then must be to develop channels free of scour, and the relations for these are likely to be quite different from those obtained by the usual regime methods. For clear water, neglecting bank sloughing, any

combination of channel width and depth which will not scour will produce a stable canal. The design of such canals will allow much more flexibility in selecting sizes than canals carrying sediment, and the lower slopes which can be used will make possible in some cases command of greater areas for the same canal length, and the production of greater hydro power. It will thus appreciably change the analysis leading to the determination of the most economical development. The science of canal design has not yet reached this degree of perfection, but study should be aimed in that direction, for it is probable that it can be attained in the relatively near future. Dr. Chien's paper is a valuable step in the direction of making possible this sort of analysis.

T. BLENCH,[1] M. ASCE.—Since the initial publication of Lacey's theory in 1929,(2) the writer has had continued experience of using, analysing, and slightly amending it, and also of extending its application practically to rivers. Justice cannot be done to the theory without a knowledge of the investigation it underwent by the Irrigation Research Institutes and various engineers of India; but the records of this work are mainly in the Annual Reports (Technical) of the Central Board of Irrigation India, that are obtainable from the library of the U.S.B.R. in Denver, Colorado and probably nowhere else in the U.S.A. As the Reports record the arguments, observations and personal opinions of a variety of research officers and co-opted experts as the subject developed, and were not intended to be formally instructive, they are almost unintelligible to anybody who has not been connected with them; in fact, the writer, who had a part in many, would not now undertake their detailed explanation. Therefore, although he disagrees considerably with the author in the discussion below, he can compliment him on a constructive and painstaking analysis.

Lacey's theory cannot be expressed in terms of the equations (1) to (3). He developed the theory in terms of a single "silt-factor" f, and never used the terms $f_{VR}$ and $f_{RS}$ except in direct or implied answer to critics. His theory may be expressed in terms of:

$$V^2/R = 1.325\, f \qquad \text{(1a)}$$

$$V = 16(R^2\, S)^{1/3} \qquad \text{(2a)}$$

$$V = aQ^{1/2} = 2.67\, Q^{1/2} \qquad \text{(3)}$$

These three equations are necessary and sufficient to fit the three degrees of self-adjustment of the types of channel considered. For theoretical discussions the following equations, deduced algebraically from the basic ones, are useful:

$$P/VR = a^2 = 7.11 \qquad \text{(7)}$$

$$V = \frac{1.35\, R^{3/4}\, S^{1/2}}{0.0225\, f^{1/4}} \qquad \text{(8)}$$

For practical design the following algebraically deduced equations are useful:

1. Prof. of Civ. Eng., Univ. of Alberta, Edmonton, Alberta, Canada; and consulting engr.

$$S = f^{5/3}/(1,788\ Q^{1/6}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

$$R = 0.47\ Q^{1/3}/f^{1/3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

There are other possibilities, including equation (2).

The equations proved most acceptable to engineers and won recommendation from the Central Govt. in a Central Board of Irrigation resolution dated 1933(a). The Govt. of the United Provinces issued canal design instructions in terms of the equations in 1932(b). However, engineers were well aware that some secondary corrections were needed. For example, although Lacey channels would run, the engineers could alter widths appreciably and the altered channels would remain in regime; so, although all Lacey channels were regime ones, not all regime ones were according to Lacey. Again, channels were designed to trapezoidal sections because they ran to practically that shape; but the design charts for trapezoidal channels (b) stopped at the lower limit of about 4 cusecs because the equations gave unreal dimensions below that limit in spite of plenty of normal channels actually running at 1 or 2 cusecs. Yet again, when Lacey expressed a belief that the "ideal" channel was probably of elliptic section (to get over this limiting discharge difficulty) engineers were quick to point out that his equations permitted them to choose, for any one case, either a certain half ellipse with its major axis horizontal or the half of the same ellipse with its minor axis horizontal—which nobody had ever observed in nature. Finally, the Province of Sind's engineers, after exhaustive site analyses, concluded that the index 1/2 in equation (3) was correct, but that "a" was very much different from 2.67. (Their channels had relatively low f's). These objections did not deter engineers from using the equations with commonsense precautions, of which one was to use them in a definite sequence so that errors, if any, would affect dimensions that did not matter.

Naturally, the Irrigation Research Institutes of the Provinces (whose research officers were ex officio members of the Central Board of Irrigation Research Committee), made most extensive field investigations of the Lacey theory. The Punjab in particular (quoted because the writer has first hand knowledge of it) posted men to sites to make observations at intervals of a few days for two or three years, and spent very considerable time in the mathematical section trying to produce improved formulas, particularly in terms of sediment diameter rather than f. These efforts are discussed by Lacey in Chapter VIII of Reference (3). If the writer remembers correctly it was the Punjab Irrigation Research Institute that had the idea of verifying the Lacey relations by inserting field data into a variety of algebraically derived equations like equations (2), (9) and (10) and checking whether the same f values resulted from each. The result was surprising, till explained later; the f's from the different equations were different, but functionally related. This peculiarity lead to analysts giving suffices to the "different f's" according to the equations from which they came, and the practice is obviously to blame for the author incorrectly using sufficed f's in equations (1) and (2) and attributing them to Lacey who was quite innocent. Two very interesting results may be quoted; (1) the f from equation (9) varied approximately as the square root of that from equation (1a); (ii) the f from equation (8) varied as an inverse power of that from equation (1a), showing that, as engineers knew, channels with large bed factor were actually "smoother" than those with small (a paradox that lies in the peculiarities of dune formation).

The cause of the confusion about "different f's" lay in the different phases of flow along sides and bed, so the use of a single f for the whole perimeter

is inadequate. Assuming a single f to be adequate and analysing systems of canals was tantamount to averaging out the "relative importance of side to bed"—to use a nontechnical description for the present. The resulting equations would refer to a physically possible set of channels, but not to all. The writer found how to split f into side and bed factors and published the result first in 1941 (c). C. King of the Punjab Irrigation Dept., who was working with him at the time, found how to introduce the width to depth ratio into the slope relation and published the result in 1943 (d). The equations to replace the original Lacey ones are most conveniently expressed as:

$$V^2/d = F_b \quad \text{.................................(A)}$$

$$V^3/b = F_s \quad \text{.................................(B)}$$

$$V^2/gdS = 3.63\ (Vb/\nu)^{0.25} \quad \text{..................(C)}$$

of which the last has been amended by the writer, after analysing Gilbert and other data, to:

$$V^2/gdS = 3.63\ (Vb/\nu)^{0.25}\ (1 + C/233) \quad \text{......(C')}$$

where C is the bed-load charge in thousandths of one percent by weight of the water flow, and the 233 is provisional till the lamentable gaps of laboratory information have been made good. (The symbolism of refs. (6,7) has been changed and the reader who desires up-to-date summarised details should consult Ref. (e). The reasons for the introduction of charge, and the limitations, will be found in Refs. (f, g)). The bed and side factors defined by equations (A) and (B) replace Lacey's f. When derived equations are compared with those of Lacey it becomes apparent that the changes do not affect the indices of measureable variables in any of his equations, and the "a" of his equation (3) was really the ratio of bed-factor to side-factor—which explains the non-technical term "relative importance of sides to bed." As "a" appeared in his various derived equations to different powers, the functional relation of the "different f's" is explained. Naturally the p,R had to be replaced by b,d when sides and beds were separated out of the wetted perimeter. The physical significance of equation (C) is something that was not apparent in the original Lacey theory. So, the only alterations to Lacey equations are in the splitting of f and in the constants, but not in the functional forms. The author expresses this correctly as "Attempts have been made by some of his followers[5-7] to improve the theory, but the basic equations as proposed by Lacey remain essentially the same, although they may be expressed in different forms with different interpretations." It is because of this that the writer has been careful, in his own writings, to explain how the credit for regime theory lies with Lindley for initial appreciation of the fundamentals, and with Lacey for producing the dynamically satisfying formulas.

The writer must disagree with Conclusions (2) and (3). The recent analyses of the classic Gilbert data (on which the Meyer-Peter and Einstein formulas and curves depend so heavily) and of river sand data in flumes by Erb and himself (f,g) show that:

i. The bed-factor, which is practically f free from side effect is a definite function of sand size and of charge (ratio of bed-load per unit time to water weight per unit time), even in flumes with rigid sides.

ii. The regime slope equation (C) is indicated when there are dunes.

iii. When dunes vanish and flow becomes supercritical the bed-factor retains its significance, but the relationship may suffer a discontinuity or, at least, a marked change; equation (C) ceases to apply.

Fig. (X) shows one of Erb's many plots for a Gilbert Sand; the bed-factor has been made non-dimensional, to test for the C relation. Fig. (Y) shows the smoothing lines for all of Erb's plots. The author's equations (4) to (6) cannot be correct since they make f vanish with charge; yet flume experiments with vanishingly small charge all show a bed with the usual dunes and a definite limiting f which is quite close to Lacey's empirical rough value of 1.9 times the square root of the mean particle size in millimeters. Presumably the formulas have been deduced over a small range of C by assuming the values given from Einstein curves; they were not deduced from Punjab field data, which does not contain charge. Incidentally Figs. (X) and (Y) should not be used without reading the context, for the lack of data at small charges, errors and special conditions of certain experiments, and different phases of bed-movement must all be considered before making application. A main conclusion from the analysis was that laboratory flume experiments to date are inadequate for accurate determination of practical parameters.

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NING CHIEN,[1] A.M., ASCE.—The writer, in full agreement with Professor Lane, holds the highest respect for Mr. Lacey, who has developed a useful set of empirical rules for the design of stable channels in Indian plains at a time when not much was known of basic fluid mechanics, not to mention the mechanics of sediment transport. This set of rules, successful as it may be in Indian plains from which it was originated, has not been generally accepted

1. Formerly Asst. Research Engr., Inst. of Eng. Research, Univ. of California, Berkeley, Calif.; now en route to China.

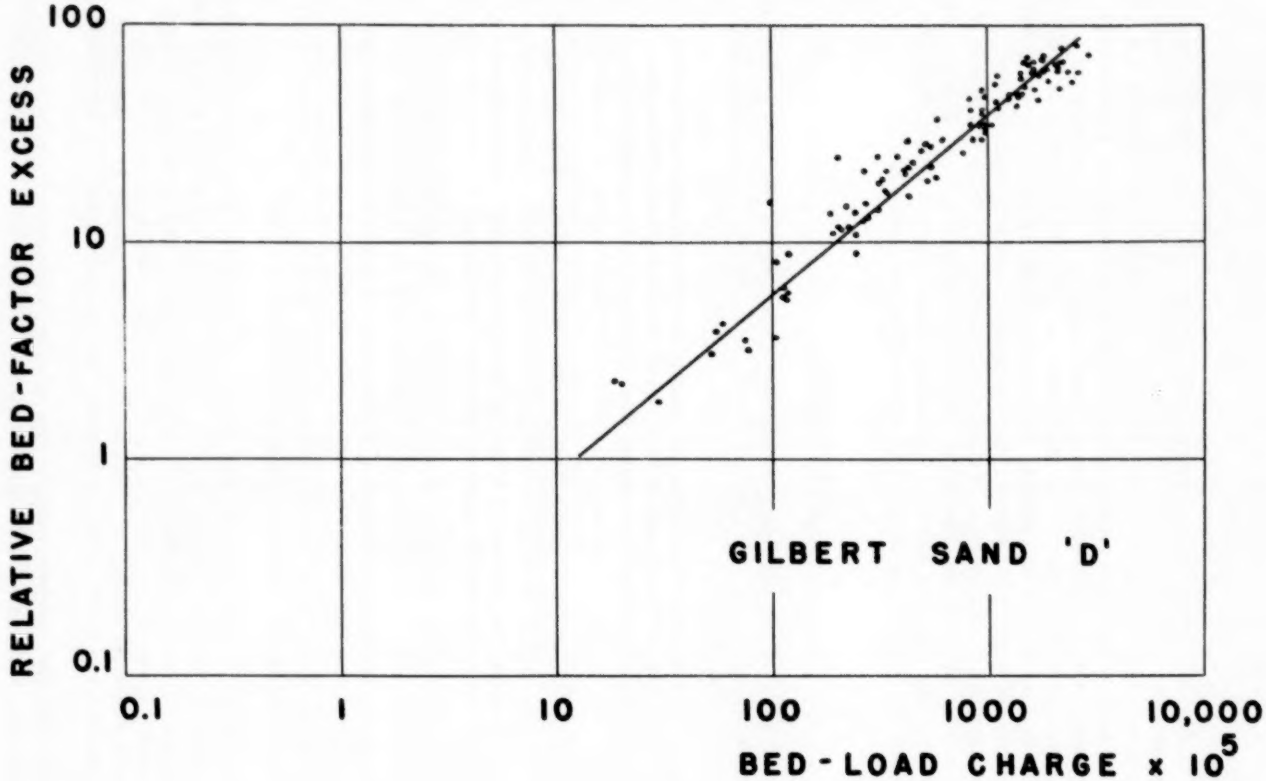


Fig. X—Typical Nondimensional Bed-Factor Data (R. B. Erb).

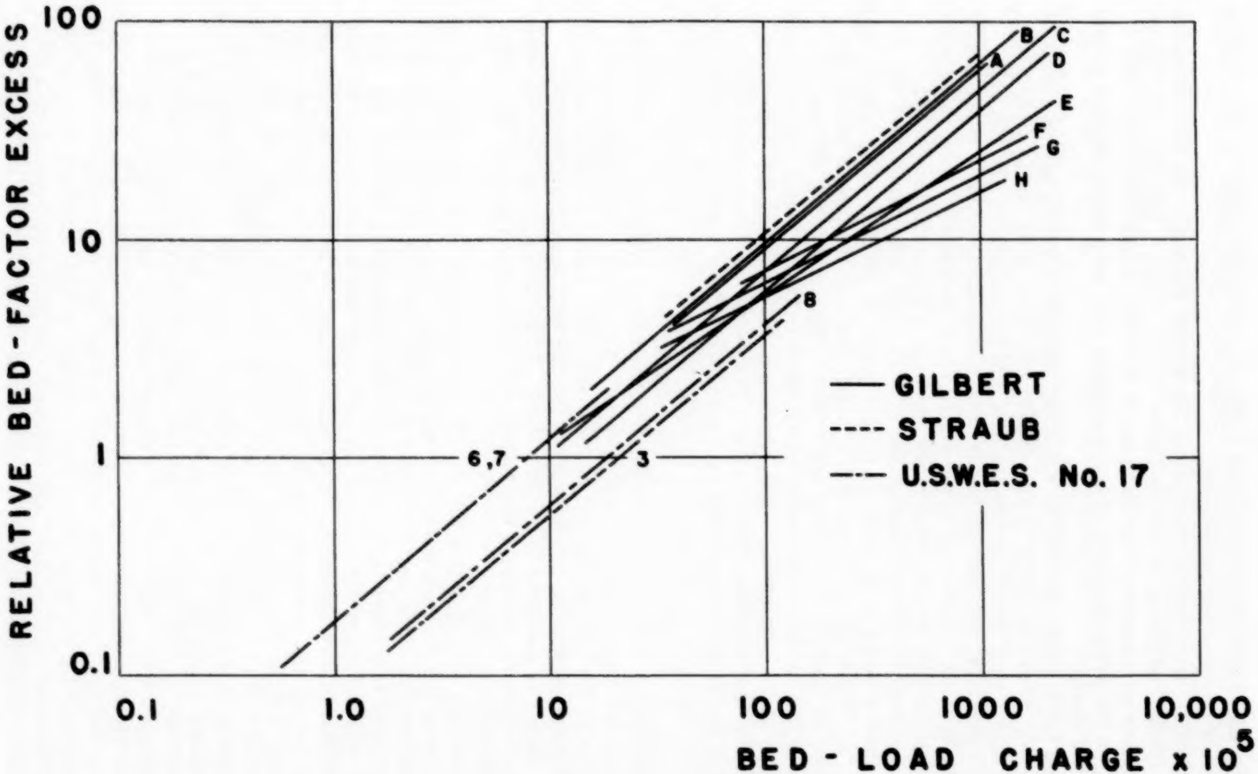


Fig. Y—Summary of Erb' s Bed-Factor Against Charge Analysis.

by engineers in other areas. This reluctance of general acceptance can be traced to the following weaknesses of the theory:

1) The negligence of the sediment supply as an independent variable makes its physical comprehension difficult.

2) No rules, empirical or analytical, have been given for the determination of the various constants, or the so-called "silt factors." Instead, their selection is based on experience which in itself is a very loose term with little meaning to the great majority of the engineers who have never worked in that part of the world.

3) The set of rules, as well as any other empirical rules, has its limits of application. There is a lack of systematic efforts to point out in clear and definite terms what these limitations are, and the engineers are left completely in the dark, not knowing under what circumstances these rules can or cannot be applied. According to the statement of Professor Lane, this limitation of applicability is much more serious than is generally suspected.

Had these shortcomings been properly corrected, long before now the regime theory would have taken its proper place in the field of hydraulic engineering, and would be used on a much larger scale at the places where the theory can be applied. It is most unfortunate that some of the followers of Mr. Lacey, out of their successful experiences in Indian plains, have adopted an attitude which is much too rigid. Instead of investigating the limitations of the rules, they consider them as basic laws with universal applicability. Instead of taking advantage of the vast amount of flume data on sediment transport made available in the last two decades to determine the effect of the sediment supply on these rules and their constants, they discredited the usefulness of the flume data which, in many respects, covered a range of conditions much wider than the regime theory ever covered. As to these over-enthusiastic supporters of the regime theory, nothing other than regime theory can be used to solve river problems, and no one but the one who has experience with regime theory is qualified to do such work. This rigid attitude not only misleads the beginners, confuses the issues, but in the long run, also discredits the regime theory itself.

The readers may question the writer, as Professor Lane did in his discussion, on what justification the writer has to judge regime theory on the basis of another theory. The writer started this problem with an open mind. He was convinced that there must exist a certain relationship between the "silt factors" and the characteristics of the sediment; and he set himself the task of finding out this relationship. After many trials, he found that in using the Einstein theory and in expressing the sediment supply by the sediment concentration, a unique relationship between the "silt factors" and the size and concentration of the sediment was revealed for the conditions in the Indian plain. Owing to the limited range of sediment size (from fine to medium sand) and sediment supply in that area, the values of "silt factors" fall within a comparatively narrow range and can be selected from experience with remarkable accuracy. Had this unique relationship not been established by using the Einstein method, thereby demonstrating the usefulness of the regime theory in that area, this paper would never have been written as it would then prove nothing. On the other hand, Einstein theory also indicates that the relationship between "silt factors" and sediment characteristics becomes a function of the hydraulics also when the conditions, especially the sediment size, are different from those existing in the Indian plain. Since regime theory, after all, is a set of empirical rules originated in the Indian plain, there is no reason to assume that these rules must apply outside of that area where the

conditions are different. On the other hand, since the development of the Einstein method was based on the basic mechanics of fluid motion and sediment transport, and since the constants involved in the method were determined under a wide range of conditions (for instance, particle size from fine sand to gravel), there is again no reason to suppose that it can be applied only to a river with fine to medium sand bed, but not to ones with coarse sand or gravel. It is based on these reasonings that the writer finally drew his conclusions as presented in his paper.

H. A. EINSTEIN,[1] M., ASCE.—The author asked the writer to answer any discussions that might be submitted after his departure from Berkeley.

While Professor Lane's and Mr. Lacey's discussions were based on the distinct understanding that the author tried in his paper to find a bridge between regime theory and the American-European approach of describing problems of sediment transport, Mr. Blench's discussion is of the type which Dr. Chien characterized as "followers." Since this writer's name was constantly used in the paper and in its discussions, he may be permitted at this place to give his own opinion about the two methods of description. First, he thinks, both want to describe the same kind of phenomena—they are comparable, therefore. The approach of the two methods is very different, however. The "bed-load function" attempts to use concepts of general fluid dynamics and its formulas where possible, changing such formulas only where the physical effect of the solid particles necessitates such changes. But even these changes are introduced only if they are physically explained. Greatest emphasis is given on physical analysis and on an ever-growing range of applicability. When Mr. Blench spends a good part of his discussion on pointing out limits of applicability for some of his formulas and constants, he may find that much of the complication of the "bed-load function" is introduced not only to talk about, but to describe such changes, which become necessary as the range of conditions is enlarged. The range of applicability for the "bed-load function is very wide today, but still needs further widening.

The "regime theory," on the other hand, is today still a set of empirical equations, to quote Mr. Inglis, and also becomes increasingly more complicated. In contrast to the "bed-load function" no attempt is made to make use of general fluid dynamics equations. Lately at least an effort has been made to straighten out the dimensional side of the equations. From year to year they become more complicated, and will in the end wind up to be identical or at least equal in content with those of the "bed-load function," since both describe the same phenomenon. The complication is inherent in the problem, and is not caused by one or the other author.

Now one is tempted to ask, which approach is better, but the question in this general form appears to the writer to be misleading. He rather believes that both methods of approach must be developed simultaneously. According to their basic difference of background, they should be used for entirely different purposes. The more scientific and unfortunately more complicated method of the "bed-load function" has a better chance to provide for a general description of the problem which incorporates a large variety of conditions into a unified form. The empirical methods, on the other hand, should be kept as simple and as easily applicable as possible, even if the field of applicability for any set of constants and exponents becomes somewhat reduced. Such a set of equations has the tremendous advantage of being easily applied in any particular case.

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The writer always tries to have two such sets of equations available and to use them in the following way: First he uses the more general and more complicated method to find the constants which must be inserted into the working equations to cover the range of conditions in question. Then, he performs the practical calculations with the approximate, but simpler equations, being satisfied that he uses the appropriate constants for the case in question. The author of Paper 620 may be particularly commended for his attempt to coordinate the two seemingly contradictory methods of describing sediment-carrying flows.

Discussion of
"OPERATION AND MAINTENANCE OF IRRIGATION SYSTEMS"

by Floyd M. Roush
(Proc. Paper 623)

ALFRED R. GOLZE,[1] M. ASCE.—Mr. Roush's paper is an excellent statement on the need for good management to keep irrigation systems operating efficiently and indefinitely, at a cost within the ability of the farmers to meet. His paper could be summarized by stating that preventative maintenance is the key to successful irrigation operations just as it is to successful operation of a municipal water or electric utility system. Replacement and improvement of structures and facilities before they are worn out or become obsolete is most important. From our experience in the Bureau of Reclamation we have found that too often the desire of the irrigation districts to hold annual costs at a low level leads to subnormal or deferred maintenance, with the eventual result that delivery of water is seriously impaired.

While pointing out that cost is an important factor in the maintenance of irrigation systems, Mr. Roush has not dwelt in any detail on this subject so that a few additional comments may be of value. Preventative maintenance at a cost within the ability of the farmers or water users to meet requires intelligent programing, covering a reasonable period of years. Schedules should be prepared listing all structures and other works which during a 3 to 5 year period (depending on the size of the system) will need attention in the form of maintenance or replacement. Structures are listed on these schedules on the basis of anticipated service life, even though there is no apparent evidence of deterioration. Structures which are no longer performing efficiently, due to changing conditions, such as changes in crop patterns requiring more or less water, are also listed. Where new developments representing current engineering practices have made existing facilities obsolete they are also to be included on the schedules for replacement or improvement. In addition, foreseeable extensions, consolidations or other improvements on the over-all project system are provided for in the schedule so that a complete work program for each irrigation system can be developed.

Once a basic schedule of this type has been prepared it can be kept current and moved along from year to year without difficulty. On non-Federal projects this schedule should be revised annually in the summer season, if necessary to support the annual budget and fall assessments. On Federal projects revision of the schedules begins in the spring and continues into the summer of each year. From this schedule, the annual budget for operation and maintenance can be developed. The cost of performing the maintenance, replacement, and improvement work on the schedule is determined, to which is added the cost of operation and maintenance such as the wages of ditchriders and other operating employees, and cost of operating equipment. A budget so prepared has to be related to the funds likely to be available.

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It is at this point that the preventative maintenance program often breaks down in that the total cost of the operation and maintenance budget may be more than the water users, acting through the Board of Directors of their District, are willing to assume. Quite often it is the replacement and improvement programs which are cut back to a lesser amount in order to balance out to the total of the District assessments. Mr. Roush properly points out that it is much more expensive to overcome deferred maintenance than it is to maintain properties on a current basis at a good standard. Needless to say, every effort should be made by the management to sell a program of high maintenance standards to its Board of Directors. In the long run it will be substantially cheaper.

In addition to a normal program of preventative maintenance, including replacement and improvements, scheduling of work requirements over a period of years will also bring out the occasional necessity for large expenditures to replace or rehabilitate important facilities such as a diversion dam, flume, or pumping plant. The cost of performing this work and at the same time maintaining normal maintenance programs could well be beyond the financial ability of the District to meet in any one year. This additional cost can be met by drawing on reserve funds or possibly borrowing money from an available source. The accumulation of reserve funds to meet major expenditures above the normal rate is a preferred procedure, because such funds earn interest for the District, instead of carrying interest costs as do borrowed funds. State laws may limit the accumulation of any substantial amount of reserved funds by irrigation districts but within what the law permits the districts should be encouraged to accumulate reserves. How large should a reserve fund be is, of course, a matter of judgment. The Bureau of Reclamation has supported a reserve equivalent to approximately one year of a project's operation and maintenance budget. Requirements beyond this amount, should they develop, would probably call for special financing involving the borrowing of funds.

Reserved funds, in addition to meeting the cost of rehabilitating or replacing major structures, also provide a source of financial aid to overcome emergencies, which frequently arise on irrigation projects. By drawing on the reserved funds, to meet damage from earthquakes, fires or floods, it is possible to continue the normal preventative maintenance program at its required rate using regularly available funds. It is axiomatic, of course, that following an expenditure from reserve funds for any purpose, arrangements must be made promptly to restore the fund to its proper balance.

Cost keeping is an essential factor in the operation of any good business. It is important in the irrigation business. The Bureau of Reclamation has in use a cost keeping system for projects in an operation and maintenance status. This system, as a minimum, requires costs to be kept separately on reservoir, carriage and canal operations and general expense. It will keep costs in whatever detail below that level that the management wants. For example, if the cost of lining a reach of canal is important it can be easily recorded during the construction period. Costs should be kept in sufficient detail to permit comparisons by years, by class of service and by facilities. The data produced will largely speak for themselves.

In support of Mr. Roush's conclusions on page 8 of his paper, it is suggested that there be added three additional factors:

9) Keep a cost accounting system in sufficient detail to know where the money goes and whether it was well spent.
10) Keep reserve funds available for replacement of major structures and for emergencies.
11) Program all physical work over a 3 to 5 year period in advance.

Discussion of
"MEASUREMENT OF CANAL SEEPAGE"

by A. R. Robinson and Carl Rohwer
(Proc. Paper 728)

RAYMOND A. HILL,[1] M. ASCE.—In the introduction to the paper on methods of Measurement of Canal Seepage the following statement appears, to which exception must be taken:

> "Of the water diverted for irrigation in the 17 Western States nearly 35,000,000 acre feet or about 40 percent is lost before it reaches the farms. On 46 operating projects constructed by the U. S. Bureau of Reclamation it was determined that approximately 25 percent of the water was lost in transit."

The writer questions the validity of these figures, believing that the indicated losses are much greater than the actual losses on these projects. The quantities reported as lost in transit are merely differences between water that is diverted and that presumed to have been delivered to farms.

The quantity of water diverted from a river into a canal system is generally known within reasonable limits. The quantities of water delivered to individual farms, however, are not known accurately, even on extremely well-managed projects; they are only approximated on most irrigation projects. Over-deliveries to farms are the rule rather than the exception. Furthermore, the quantities of water reported as having been returned to the river through wasteways are too frequently no more than guess by a gate tender.

In brief, the quantities of water reported by the U. S. Bureau of Reclamation and others as lost in transit represent only water not accounted for by measurements. Such measurements are generally inadequate and tend to exaggerate the apparent loss of water due to seepage from canals.

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## PROCEEDINGS PAPERS

The technical papers published in the past year are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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### VOLUME 81 (1955)

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c. Discussion of several papers, grouped by Divisions.